

Carbon footprint of a Cavendish banana supply chain

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Abstract

Purpose Bananas are one of the highest selling fruits worldwide, and for several countries, bananas are an important export commodity. However, very little is known about banana's contribution to global warming. The aims of this work were to study the greenhouse gas emissions of bananas from cradle to retail and cradle to grave and to assess the potential of reducing greenhouse gas (GHG) emissions along the value chain.

Methods Carbon footprint methodology based on ISO-DIS 14067 was used to assess GHG emissions from 1 kg of bananas produced at two plantations in Costa Rica including transport by cargo ship to Norway. Several methodological issues are not clearly addressed in ISO 14067 or the LCA standards 14040 and ISO 14044 underpinning 14067. Examples are allocation, allocation in recycling, representativity and system borders. Methodological choices in this study have been made based on other standards, such as the GHG Protocol Products Standard.

Results and discussion The results indicate that bananas had a carbon footprint (CF) on the same level as other tropical fruits and that the contribution from the primary production stage was low. However, the methodology used in this study and the other comparative studies was not necessarily identical; hence, no definitive conclusions can be drawn. Overseas transport and primary production were the main contributors to the total GHG emissions. Including the consumer stage resulted in a 34 % rise in CF, mainly due to high wastage. The main

potential reductions of GHG emissions were identified at the primary production, within the overseas transport stage and at the consumer.

Conclusions The carbon footprint of bananas from cradle to retail was 1.37 kg CO₂ per kilogram banana. GHG emissions from transport and primary production could be significantly reduced, which could theoretically give a reduction of as much as 44 % of the total cradle-to-retail CF. The methodology was important for the end result. The choice of system boundaries gives very different results depending on which life cycle stages and which unit processes are included. Allocation issues were also important, both in recycling and in other processes such as transport and storage. The main uncertainties of the CF result are connected to N₂O emissions from agriculture, methane emissions from landfills, use of secondary data and variability in the primary production data. Thus, there is a need for an internationally agreed calculation method for bananas and other food products if CFs are to be used for comparative purposes.

Keywords Bananas · Carbon footprint · Fruit · ISO 14067 · PCR

1 Introduction

Agriculture has traditionally not been a sector associated with environmental problems in the same way as the transport sector, energy sector and heavy industries. In the 1960s and 1970s, there was a growing awareness that agriculture could cause environmental problems. Books such as “The Silent Spring” brought the toxicological impact of pesticides and other pollutants into focus. At the same time, many rivers, lakes and other water bodies suffered the effects of algae blooming and other effects of eutrophication. Largely based on these concerns, organic production systems became widespread. In the last 10 years, there has been an increased focus on the problems caused by global

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warming. In parallel, there has been a general shift from end-of-pipe to preventative solutions and from only considering point sources to studying entire systems.

Several methods, among them life cycle assessment (LCA) and carbon footprinting (CF), have been developed and used to study a wide variety of goods including agricultural products. LCA can be used to study the entire life cycle of a product, beyond just the production phase, and summarize the environmental impacts of whole value chains, e.g. from production until consumption. This is important as greenhouse gas (GHG) emissions of the whole value chain from farm to fork is high, representing approximately 31 % of the total climate gas emissions (EIPRO 2006) in the EU.

LCA studies of foods generally show that products of animal origin tend to carry the highest GHG burden (European Commission 2006; Williams et al. 2006; Sim et al. 2007) and have a much higher CF than products derived from plants. However, products derived from plants can have a considerable climate impact, e.g. Stoessel et al. (2012) mentioned cucumbers and tomatoes grown in heated greenhouses, products transported by air and products originating from systems with low yields per hectare. Several other examples exist, e.g. the work of Hospido et al. (2009) on lettuce.

The cultivation of fruit crops is a profitable agricultural activity in many tropical countries. Fruits are traditionally regarded as being associated with a low environmental impact compared to herbaceous crops and other food products (Cerutti et al. 2011). However, tropical agriculture and especially bananas have been associated with biodiversity loss, high water use, and contamination of air, water and soil (Worobetz 2000). As a consequence, several banana producers have devoted considerable effort into improving the management of plantations, packing plants, transport and storage to reduce the environmental impact (e.g. World Banana Forum 2012, Working Group on Sustainable Production Systems and Environmental Impact).

Bananas are among the most consumed fruits in the world, in Norway and Sweden the highest seller of all fruits (SCB 2010). The main producers of bananas for the European market are Latin America (FAOSTAT 2009), resulting in considerable transport distances for a fruit that is susceptible to spoilage. Considering the fact that bananas is one of the most important crops in the world, there are few published CF studies of this product (Evans and Ballen 2010). Until recently, the only published LCA or CF results for Cavendish bananas is the cradle-to-retail CF calculated by Berners-Lee (2010) (0.480 kg CO₂-eq per kilogram product) and Wallén et al. (2004) (0.45 kg CO₂ per kilogram banana). However, in Wallén's study, the banana CF was assumed to be the same as the apple CF, and the result published by Berners-Lee built on Wallén's figures. Dole published in 2011 a carbon footprint study covering the life cycle stages from plantation until the Regional Distribution

Centre in Germany (Luske 2010). This study is an expansion of this study covering the life cycle stages until consumption in Norway. The aim of this work was to study the greenhouse gas emissions of bananas from cradle to retail and cradle to grave using ISO standard 14067 under preparation and to assess the potential of reducing GHG emissions along the value chain

2 Methods

Standard carbon footprint methodology was employed following ISO 14067 (Draft International Standard, DIS) version (ISO 2012). For some methodological choices, ISO 14067 does not give clear guidance. In these cases, choices were made based on knowledge of the studied system, the PAS 2050-1 (BSI 2012) on horticultural products and the product category rule (PCR) for fruits and nuts of the International EPD System (2009). The reason for choosing ISO 14067 rather than the more established and widely used guidelines PAS 2050-1 and GHG Protocol (WRI and WBCSD 2011) is that ISO standards have a very high standing globally and is in fact made into law in some countries.

2.1 Goal and scope

The main aim of this study was to document the global warming impact of Cavendish bananas along the value chain. Two systems were studied: cradle to retail (from production to retail) and cradle to grave (from production to consumption).

The results should be of interest to researchers and others engaged with environmental issues related to food production. The results could also be useful for actors along the value chain to identify and prioritize emission reduction possibilities. Several methodological challenges have arisen during the documentation of GHG emissions, and these are discussed further on in the article.

2.1.1 Functional unit

The main system boundary studied was cradle to retail. In addition, a cradle-to-grave CF, e.g. from production to consumption, was calculated as an extension of the cradle-to-retail study with the consumption stage added.

The functional units were

- 1 kg banana sold to a customer in Norway
- 1 kg banana consumed in Norway

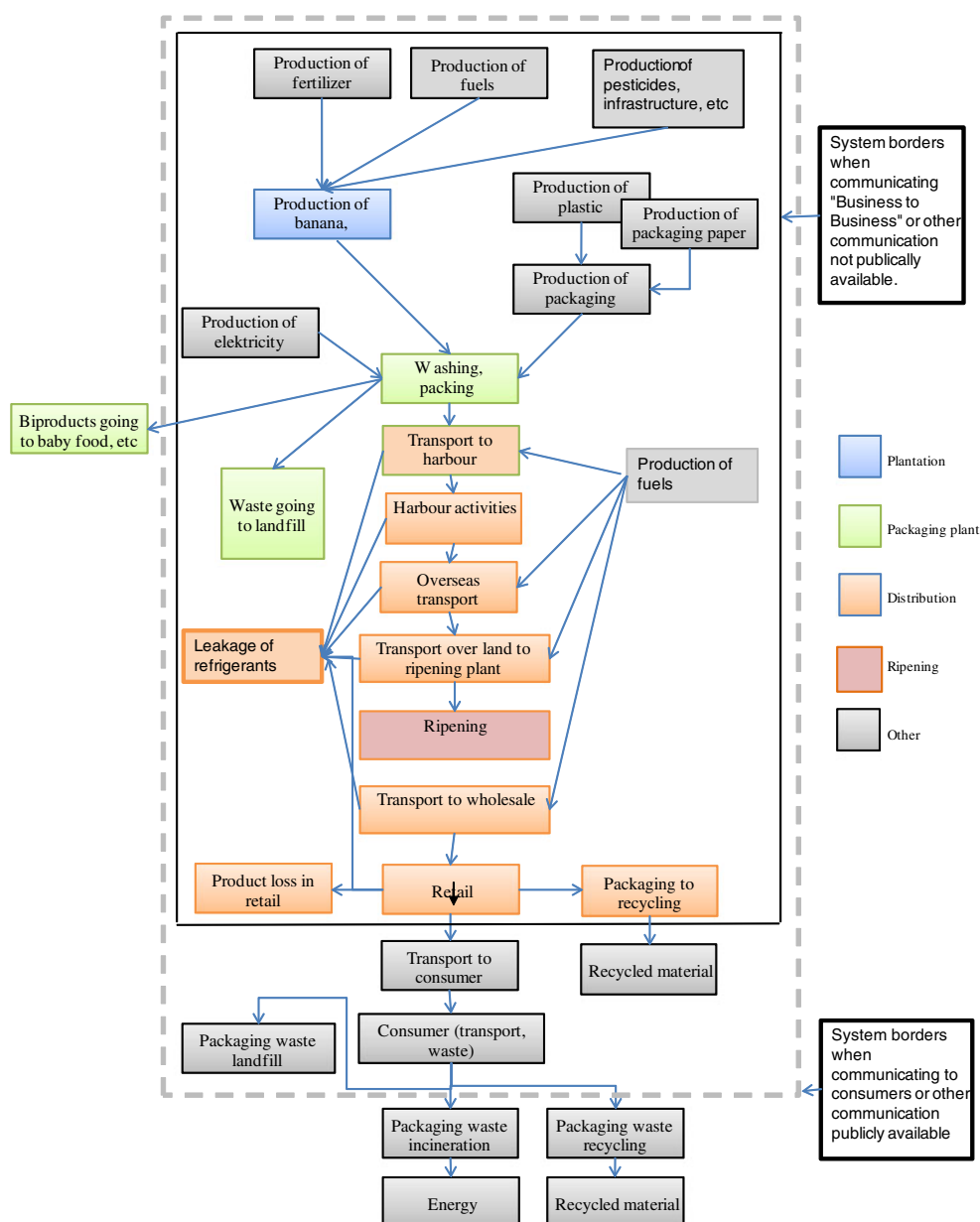
All results are in addition given as CF per 1 kg eatable product and per nutrient density unit as defined by Smedman et al. (2010).

2.1.2 System boundaries

System boundaries concern both which life cycle stages are included in the assessment and what processes within the included life cycle stages are taken into account. In this study, the main system border was “cradle to retail” (Fig. 1). According to ISO 14067, it is a partial assessment that can be used in communication not intended to be publicly available, e.g. business-to-business communication. Thus, the results of a cradle-to-retail assessment cannot, according to ISO 14067, be communicated to the general public. If a CF assessment is to be made publicly available, the system must be assessed all the way from cradle to grave. The term cradle to grave signifies all life cycle stages from primary production to end consumption. In this study, the digestive process and wastewater treatment

processes are not included in this assessment. Several studies, such as those of Sonesson et al. (2004) and Muñoz et al. (2008), argue that the digestive system must be included since this stage and the following wastewater treatment stage are important contributors of the environmental impact in the life cycle of the products. No study has been found that argue against the inclusion of the digestion, but few LCAs of food include this stage. Should digestion be included in the term cradle to grave defined in ISO 14067? In this study, we consider that the human body is a part of nature and when the food is ingested the energy and materials are returned to nature. Another reason for not including the digestive process was that it is difficult to find a link between the amount of a certain food a human being ingests and one or several of the function(s) a body have in a quantitative way.

Fig. 1 System description



The boundary between the banana production system and other product systems was the point where materials or energy enter into the next system, in this study interpreted as the point where waste enters recovery plant. The exception was landfilled waste, for which all emissions were included in this product system. The reason for including all landfill emissions is that the landfilled waste does not enter into another product system.

Business trips, commuting, human digestion and human labour (e.g. from the growing of food to workers) were excluded from both the cradle-to-retail and cradle-to-grave assessments. The reason for not including human labour was that the processes connected to maintaining the body have several functions, of which work is just one. The allocation between different functions is difficult. The reason for not including commuting and business transport in the system is the difficulties of setting the boundary. Should only the persons directly involved in the production be included or also other employees, e.g. the sales department employees? Another problematic issue is the allocation between purposes when several purposes are combined in one trip.

The use of transport animals was included for both the cradle-to-retail and cradle-to-grave CFs because these are kept for the sole purpose of working in the plantation. Emissions from the production of capital goods used in the plantations; transportation (vehicles, vessels, harbours, boats); and production of inputs (fertiliser, pesticides, fuels) were also included in both the CF assessments.

Consumer transport and consumer wastage were included in the cradle-to-grave CF. “Consumer wastage” signifies emissions needed to produce, process, package, store, transport, ripen, etc., bananas to replace the amount wasted by the consumers. The fruit is assumed to be eaten raw and kept at ambient temperature; hence, no emissions from storage and cooking are included.

All processes contributing <1 % of the total CF were excluded. The total cutoff was estimated and was shown to be <5 %.

2.2 Biogenic carbon

Land use change (LUC) emissions shall, according to ISO 14067, be taken into account using IPCC Guidelines, and the IPCC Guidelines state that lands unchanged for 20 years do not need to be reported under the tier 1 approach (IPCC 2006b).

ISO 14067 also states that soil carbon change effects may be included, but adds that no internationally accepted method to calculate this effect exists. As defined by Bessou et al. (2013), the banana production system is perennial and the carbon in standing biomass should be taken into account when calculating the carbon footprint.

This is, however, a complex issue, and no methodology is today available that fully incorporates a perennial system into CF studies (Bessou et al. 2013).

According to ISO 14067, “GHG emissions and removals arising from fossil and biogenic carbon sources and sinks shall be included in the CF and shall be documented separately in the CF study report”. There are ongoing discussions (November 2012) about how this shall be interpreted. Thus, the amount of biogenic carbon has not been documented separately in this study. Biogenic carbon in the products is released to the atmosphere, after use of the products, as CO₂ or CH₄. Since the amount of carbon absorbed from the air is equal to the amount emitted back after use, the impact of biogenic CO₂ is set to 0. The impact factor of CH₄ from biogenic sources is set to 22.25, which is the normal impact factor 25 minus the effect of CO₂, as calculated by Wicke et al. (2008).

2.3 Allocation

Mass allocation was used to allocate emissions between premium export quality bananas and by-product going to baby food production. The reason for using this method rather than choosing the options preferred according to ISO 14044 was that there was no possibility to split processes, and system expansion using substitution was not possible due to difficulty in identifying a substitute product. Mass allocation was preferred over economic allocation because both products are for human consumption and prices used economic allocation is subject to market fluctuations. In the transport from Germany to Norway onboard a combined passenger/cargo ship, a two-step allocation procedure was used. In the first step, economic allocation was used between passenger and cargo freight. In the second step, “ground space” allocation was used between different cargos aboard the same ship. In the first step, the cargo part of emissions was determined by the percentage of the ship owner’s total earnings coming from cargo freight (mass allocation between cargo and passengers would not be meaningful). In the second step, the emissions of the bananas vs. other cargo was based on “space,” e.g. the ground space in “lane meters” occupied by the truck containing the bananas. The reason is that space, rather than mass or volume, was the limiting factor for the cargo capacity on board. Emissions in transports from wholesale to retail were allocated according to mass allocation. Retail and wholesale storage emissions were allocated using economic allocation. Total emissions were divided on the turnover of the shop/storage facility, and the emissions were calculated using the products’ prices. The reason behind the use of economic allocation in this case is that the companies have detailed data on yearly turnover and yearly use of inputs.

ISO 14067 refers to ISO 14044 in the case of allocation; the text is almost identical. ISO 14044 states: “Allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, if allocation is made to usable products (e.g. intermediate or discarded products), then the allocation procedure used for such products entering the system”. The text can be interpreted as allowing combined allocation, but saying that whatever method is chosen, it must be consistently applied to similar situations. This means that combined allocation could be allowed according to the standard.

2.4 Data sources

In general, primary activity data have been used for most processes and secondary data have been taken from the Ecoinvent database, version 2.2. The banana producer provided primary activity data for the value chain from plantations in Costa Rica to ports in Europe (see Luske 2010 and Table 1 in this article). Emissions from overseas transport from Costa Rica were calculated using Ecoinvent processes (Ocean Freighter) modified by using primary data on fuel usage and capacity utilisation. This enabled a more precise calculation of the infrastructure emissions. Emissions from ports in Europe to ripening plants were calculated using primary data for the distances and degree of load capacity utilisation and database data for emissions per distance unit. Primary data from one ripening plant were used based on yearly average per product unit processed.

Emissions from ripening plant to and including retail shop were calculated using average primary activity data from two major Norwegian retail and wholesale companies. Emissions from the consumer part of the value chain were calculated using data from other studies (see the relevant section). For the waste generated in Norway, average transport distances to waste treatment were assumed.

3 System description

3.1 Primary production

The two banana plantations that were inventoried for this study were located on the eastern side of Costa Rica, close to the Atlantic coast. The two plantations produced a yearly yield representing approximately 6 % of the total production in Costa Rica. The banana plants are of the Cavendish variety and propagated from offshoots from a mother plant. Nine months after planting, the first bananas can be harvested and the plant is cut down. The plant has in turn developed a new offshoot (sucker) which is left to grow, and additional offshoots that develop are cut down. Bananas from this plant can be harvested after 14 weeks. The

procedure is repeated and this system goes on for many years. Every 10 years, a production area goes through a 6-month fallow period where the plants are removed, first by desiccating them with herbicide and later through the use of machinery to prepare the soil. Cover crops are planted in between cycles, but there were insufficient data to assess the environmental impacts of this practice. After plant removal, all plantation infrastructure is dismantled. The infrastructure consists of a propping material (aerial cable and support posts) to support the plants and a cable way to transport bananas. Because of the fallow period, there is a total of 15 months without production. In several LCA studies, the life cycle inventory is shown for only the full productive years of a perennial crop system and does not account for the nonproductive years at the beginning of the farm stage, or for the decreasing productivity at the end of the crop cycle (Bessou et al. 2013). This study takes into account the fallow period in the banana crop cycle in the calculations by averaging all emissions in a 10-year period on 8 years and 9 months of full crop production. According to the banana producer, there is no decrease in productivity at the end of the 10-year production cycle. Data for the plantations were available for only one year, 2008. This is not ideal since the yields can vary significantly from year to year (Bessou et al. 2013). Because of the large area of the plantations (2,900 ha) and the fact that different blocks of the plantations are in different parts of the 10-year cycle, these yield differences are assumed to be evened out.

3.1.1 Fertilizer use

The major sources of GHG emissions associated with crop production are soil nitrous oxide (N_2O) emissions, soil CO_2 and methane (CH_4) fluxes, and CO_2 emissions associated with agricultural inputs and farm equipment operation (Robertson et al. 2000). Nitrous oxide emissions are often a major contributor to the CF in the agricultural phase. Crop systems emit N_2O directly from the application of mineral and organic nitrogen, produced through nitrification and denitrification in the soil, and also indirectly when nitrogen is lost from the soil as some form other than N_2O (NO_x , NH_3 , NO_3) and later converted to N_2O off the plantation. N_2O emissions and nitrate leaching vary with the amount of nitrogen fertiliser applied and the combined effect of rainfall, soil temperature and texture, and crop rotation (Adler et al. 2007). Bananas have a high requirement for nitrogen and potassium and have the highest fertilization rate per hectare of all food crops (Soh 1997). In this case, mineral nitrogen fertiliser was applied manually in the form of urea and ammonium nitrates. A small amount of the fertilisers were foliar fertilisers which were applied by aerial sprayings. The impact from fuel use of aerial sprayings was included in the inventory for pesticide spraying. The IPCC tier 1 (IPCC 2006a) approach was used to calculate

Table 1 Inventory table

Parameter	Value	Source
Plantation		
Infrastructure, concrete	7,317 kg/ha	Direct measurements by authors and company primary data
Infrastructure, steel cables	348 kg/ha	
Infrastructure, PP thread	19 kg/ha	
Mules per tonne banana harvested	0.001	Banana company primary data
Amount of concentrated feed pr mule pr day	4.5 kg	
Processing plant		
Amount of organic production waste per kilogram banana	71 g	Banana company primary data
Overseas transport, container		
GHG emissions large container ship, operator 1. Average South America–Europe	115.8 g CO ₂ /TEU*km	Transport company 1 average primary data
GHG emissions large container ship, operator 1. Average within Europe	99.5 g CO ₂ /TEU*km	
GHG emissions large container ship, operator 2. Average South America–Europe	105.7 g CO ₂ /TEU*km	Transport company 2 average primary data
GHG emissions large container ship, operator 2. Average within Europe	127.9 g CO ₂ /TEU*km	
Refrigerant emissions, large container ship, operator 2	0.08 g CO ₂ -eq per kilogram banana	Banana company primary data
Net load per TEU	9.88 tonnes bananas	
Heavy fuel oil consumption, small container ship, per trip Costa Rica to Oslo	106.7 g/kg banana	
Refrigerant emissions, small container ship, one trip	13 g CO ₂ -eq per kilogram banana	http://sea-distances.com/
Distance Costa Rica–Bremerhaven	5,093 nautical miles	
Distance Bremerhaven–Oslo	428 nautical miles	
Transport from Hamburg to Kiel		
Distance	99 km	http://www.viamichelin.com/
Transport mode	Lorry, >32 t, Euro 4	Wholesale company data
Transport from Kiel to Oslo		
Distance	335 nautical miles	http://www.viamichelin.com/
Share of earnings from cargo	15 %	Shipping company primary data
Emissions	400 g CO ₂ /lane meter and kilometres travelled	
Space taken by truck	13 lane meter	Direct measurements by authors
Load per truck	21.1 tonnes	Wholesale company primary data
Ripening		
Electricity	0.046 kWh/kg	Wholesale company primary data
Ethylene (I)	0.36 g	
Transport to waste treatment facility		
Distance waste collection (first stage)	19 km	Waste collection companies
Distance waste transport to central collection point (second stage)	52 km	
Distance waste transport to landfill (third stage)	2 km	
Distance waste transport to incineration (third stage)	14 km	
Distance waste transport to material recycling, plastics (third stage)	836 km	
Distance waste transport to material recycling, other than plastics (third stage)	444 km	

TEU twenty foot equivalent unit (a banana container equals 2 TEU)

the direct and indirect N₂O emissions from fertiliser use, nitrate leaching to water and ammonia to air. Emissions from urea application were estimated with a 20 % volatilization rate according to the IPCC guidelines (IPCC 2006a). The IPCC

tier 1 approach is linked with a high uncertainty due to the roughness of the estimates for tropical conditions, but due to lack of more detailed data, it was not possible to use a higher-tier method.

The emissions from fertiliser production were calculated using Ecoinvent average data, 8.16 kg CO₂-eq per kilogram N for ammonium nitrate and 3.07 kg CO₂-eq per kilogram N for urea.

3.1.2 Land use change and soil carbon change

LUC effects were assumed to be zero because the studied plantations were more than 20 years old. Since ISO 14067 does not give guidance on the calculation of LUC effects, the requirements of PAS 2050 were used.

Soil carbon change (SCC), defined as emissions due to the GHG emissions and removals occurring as a result of soil carbon change not classified as LUC, was not included due to a lack of an internationally agreed calculation procedure. According to ISO 14067, SCC emissions should be taken into account in accordance with internationally recognised methods such as the IPCC Guidelines, but mentions that there is ongoing research to develop methodology and models for the inclusion of soil carbon change in GHG reporting. Little change in the soil carbon content is expected because there is very little soil tillage, many plant residues are left on the ground, and the soil is only left bare in the fallow periods.

3.1.3 Pest and disease control

Detailed data for pest and disease control were not available for this study. Only the amount of chemicals used was known. Pesticide production emissions were calculated using Ecoinvent average emissions for pesticides (9.4 kg CO₂-eq per kilogram pesticide).

3.1.4 Use of plastics

On the plantation, bananas are covered with plastic to protect the fruit from insects during their growth. The plantations reuse the plastic to minimize plastic use. On average, one bag can be used three times before becoming damaged and in need of replacement. The discarded plastics are collected and sent for recycling. The use of plastic per hectare has been estimated by multiplying the number of bunches that are harvested per hectare per year with the weight of a plastic bag (0.025 kg). The plastic is used three times before it is disposed off, giving a reuse rate of 300 %. Plastic is also used for wrapping banana clusters at harvest to protect from damage. This plastic is reused a large number of times at the plantation and not taken into account in the CF study.

3.1.5 Harvesting

Bananas are harvested manually followed by transport from the field to the on-farm packaging facility via steel cables

powered by mules which function like a conveyer belt. The impact from the mules is included in this study. The impact was calculated based on IPCC Guidelines on N₂O and CH₄ from droppings, CH₄ from enteric fermentation and from the feed rate.

3.1.6 Yields

The yields for 2008 were used as the basis for the study. Bananas meeting the quality criteria are sold for export and the rest to a food manufacturing company specializing in baby foods. The average yield per hectare (45.78 tons/ha) for the two plantations was 24 % higher than the average Costa Rican banana yield for 2010 (FAOSTAT 2012).

3.1.7 Packing at farm

At the packing facility, the fruits undergo an initial quality check and are cut into “hands” consisting of five to seven “fingers” (number of individual banana fruits). Thereafter, bananas are washed with water containing a small (0.5–1 %) percentage of chlorine. The water is recycled and reused for up to 6 days within the facility. In this study, water consumption was not included due to lack of data.

In the packing facility, electricity is used mainly for lighting and for operating pumps that extract water from wells. Bananas are also transported within the facility on conveyor belts powered by electricity. Electricity is taken from the Costa Rican grid. The emission factor for the Costa Rican grid of 0.1165 kg CO₂-eq per kilowatt-hour (Ministerio de Ambient y Energía, 2007) is relatively low due to hydropower generation. On occasion, the power supply fails and diesel generators generate power.

The bananas are packaged in cardboard boxes with a plastic liner. Material use is 70.9 kg of cardboard per tonne and 1.4 kg of low-density polyethylene (LDPE) per tonne banana. The packaged boxes are fumigated to avoid microbial growth during transport. The boxes are packed together on pallets; the standard pallet contains 48 boxes. The pallets are then loaded into containers (20 in each) that are transported from the packaging facility to the port terminal in Moin, situated on the Atlantic Coast of Costa Rica.

Waste from the packing facility is landfilled. The waste largely consists of banana stems, in addition to some waste bananas and leaves. IPCC methodology was used to calculate CH₄ emissions from landfill. The degradable organic carbon value (0.24) for “Garden and park waste” and “Other (non-food) organic putrescibles” was used. The corresponding value for wood and straw waste was 0.3. The CH₄ correction factor was set to 0.6, an average of the factors for deep unmanaged landfills or high groundwater landfills (0.8) and other landfills (0.4). A biogenic CH₄ impact factor of 22.25 was used.

3.2 Transports from Costa Rica to Norway

Packaged bananas are sent to the port in Moin by a combination of trucks (60 %) and rail (40 %). The pallets are loaded into special purpose ships (“pallet ships”) and shipped to Hamburg or Antwerp followed by truck transport to Kiel, and subsequently shipping by combined passenger/cargo ships to Oslo, Norway. From the port, bananas are transported by truck to a ripening facility in Oslo.

3.3 Ripening

Bananas are ripened by exposure to ethylene gas (C_2H_4) in purpose-built chambers with controlled air temperature and relative humidity. The process is carefully controlled and adjusted to avoid over-ripening of fruit and, hence, minimizing waste before transportation to retail.

3.4 Distribution in Norway and retail

After ripening, the product is sent to wholesalers, stored and thereafter transported to retailers. Average distances calculated by DMF (the Norwegian Retail Environmental Forum) were 120 km from ripening to wholesale storage and 150 km from wholesale storage to retail shop. In retail, the product is kept at room temperature. Bananas are mostly sold unpackaged. Some customers choose to wrap the bananas in a plastic (LDPE) bag; others do not use packaging. In this study, it was assumed that half the customer used plastic packaging weighing 15 g.

3.5 End consumption

Emissions from consumer transport are calculated according to numbers from Milà i Canals et al. (2008), where average distances of 0.185 km by car and 0.00085 km by bus were calculated. It is also assumed that the products are kept at room temperature and eaten raw; hence, no emissions from cooking and storage are included.

3.6 Product wastage

Product wastage occurs along the whole supply chain. No emissions are allocated to banana waste at the packing plant because such waste has no commercial value and the calculations are based on the actual packaged output. However, the organic waste from the packaging plant is landfilled and the emissions from this waste are thus accounted for. Wastage from packaging plant to wholesale has been estimated by the companies along the value chain. The value for wastage in retail has been calculated on the basis of an average (2.9 %) from 30 retail shops in Norway. The consumer wastage rate was not measured in this study. An

average consumer wastage rate of 26.3 % was assumed (average for fruit; WRAP 2008). Due to wastage, a higher amount had to be grown, processed, stored, transported, etc., to deliver the same amount to the shop or consumer. This has been taken into accounting in the modelling.

3.7 Infrastructure

Greenhouse gas emissions for plantation infrastructure were calculated using primary data on the material used and their lifetime. Only emissions from raw material production were included due to lack of data on component manufacture. Emissions from other infrastructure mentioned above (transportation and production of inputs) were included via the Ecoinvent processes used to calculate emissions. Emissions from other infrastructure such as the processing plant and the ripening plant were not included because data were not available. Harbor infrastructure emissions were taken from Ecoinvent.

4 Results

The cradle-to-retail CF of the studied banana supply chain was found to be 1.37 kg CO_2 -eq per kilogram. Assuming that the peel constitutes 34 % of the fruit, the CF for the edible part thus was 2.2 kg CO_2 per kilogram. Nutrient density as defined by Smedman et al. (2010) was 0.73 based on 100 g edible fruit. The CF per unit density was thus $0.22/0.73=0.28$ kg CO_2 -eq per nutrient unit.

The corresponding results for the cradle-to-grave CF was 1.84 kg CO_2 -eq per kilogram banana, 2.9 kg CO_2 per kilogram edible banana and 0.38 kg CO_2 -eq per nutrient unit. In the remainder of the text, only the results for product including peel will be discussed since the proportion of edible product differs from banana to banana and set factors differ from country to country. The cradle-to-grave results are associated with high uncertainties, and therefore the focus will be on the cradle-to-retail CF.

Figure 2 shows the distribution of GHG emissions in the life cycle stages of the cradle-to-retail assessment and demonstrates that transport and storage are the main contributors to the CF (67 %). Primary production gives the second largest impact at 16 %, followed by packaging and product wastage. Packaging includes the banana box, pallets and all other package elements. Emissions caused by “product wastage” are emissions needed to produce, process, package, store, transport, ripen, etc., bananas to replace the wasted amount.

Table 1 gives a more detailed view of the distribution of GHG emissions. The hot spot of the value chain is overseas transport from Costa Rica to Europe. Primary production is the second largest source of GHG emissions. Transport from Kiel to Oslo, retail and retail waste also give significant

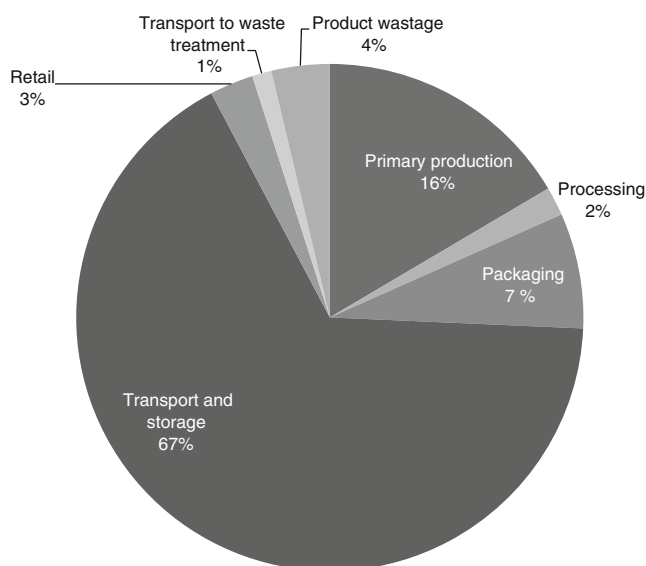


Fig. 2 Distribution of GHG emissions cradle to retail

contributions, whilst the ripening process and transports within Norway have a minor effect on the CF.

Figure 3 shows a breakdown of the GHG emissions of the primary production phase. Methane emissions from plant waste landfill had the single largest impact on the CF, followed by N_2O emissions from soil due to fertiliser use.

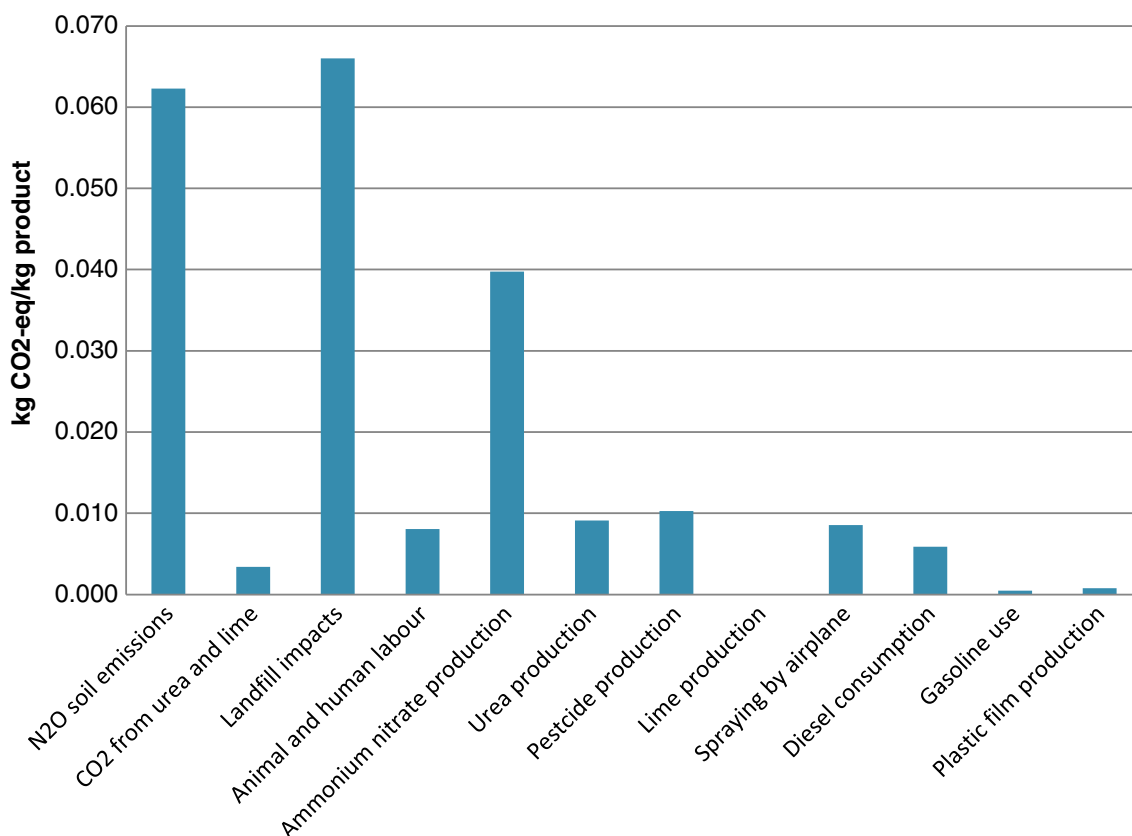


Fig. 3 Breakdown of GHG emissions from primary production

When examining individual GHGs, CO_2 was the main contributor to the CF, with 84 % of the total emissions deriving from the transport and storage of bananas (Fig. 4). CH_4 emissions arose mainly from waste handling. Nitrous oxide emissions contributed little to the overall CF (5 %) and occurred mainly in the primary production stage.

5 Discussion

5.1 Carbon footprint

The cradle-to-retail result in this study was 0.247 kg CO_2 -eq, higher than the corresponding result by Luske (2010), i.e. 22 % higher. The reason was partly that the distance to retail in Norway is higher than the distance to retail in Germany, partly because some impacts are not considered in the Luske, methane from landfills and infrastructure in the plantations. Another reason was that a much lower number for the production and transport of fuel (diesel and heavy fuel oil) was used in this report than by Luske. However, Luske used economic allocation between premium bananas and product going to baby food, whereas in this study, mass allocation was used.

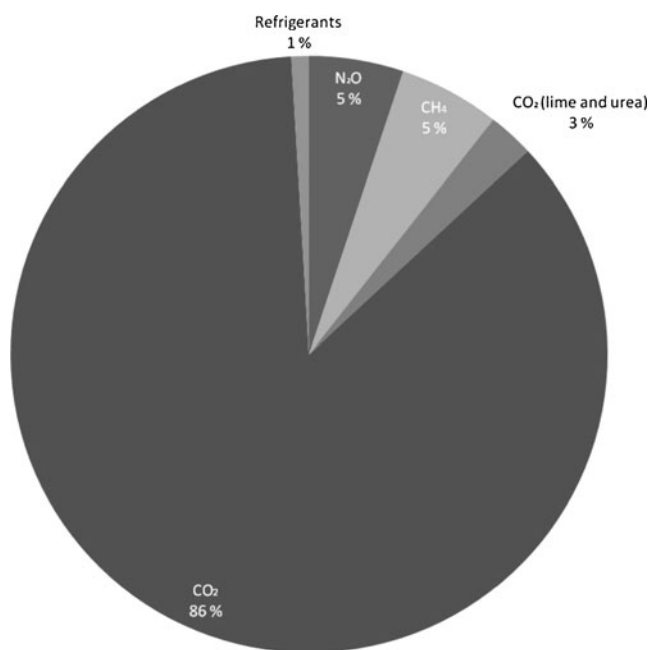


Fig. 4 Distribution of emissions between greenhouse gases, cradle to grave

This gave a slightly lower contribution from primary production in this study than in the Luske study.

The cradle-to-grave CF for the bananas in our study was found to be 34 % higher than the cradle-to-retail result, even though the product was assumed to be eaten raw and stored at room temperature. The transport from shop to home was also conservatively estimated. The transport data were taken from the UK, a country with a higher population density than Norway and, thus, presumably shorter distances from shop to home and a wider range of public transport options. The dominating source of GHG emissions after farm gate is, in many cases, CO₂ from fossil fuel use (Garnett 2011). This is also the case in this study where transport and storage are the main contributors to the CF. In fact, CO₂ remains the main contributor to the CF when including the farm stage.

Shipping tends to be very energy-efficient (Milà i Canals et al. 2007), but in this study, the impact of shipping is rather high, for reasons discussed in Section 5.3.

The second largest contribution to the cradle-to-grave CF is the consumer's high wastage rate. This wastage rate has not been calculated in Norway for bananas, but instead relies on figures from the WRAP (2008) study; thus, the CF can be quite uncertain. This fact, together with the uncertainty concerning consumer transport, gives a high uncertainty in the results, one of the main problems of cradle-to-grave CFs for food. This high uncertainty makes comparability between products difficult, which could be confusing for consumers. On the other hand, informing the consumers of the effect of the wastage can give them an extra incentive to reduce this waste.

One of the issues that can lead to differences of the end result is the choice of secondary data. The impact of fuel

production can be very different from source to source. In this study, Ecoinvent data (heavy fuel oil (HFO) at regional storage, RER, U) have been used, amounting to an emission of 0.45 kg CO₂ per kilogram HFO. Other sources (highest number Ecoinvent process: "HFO at regional storage, CH, U"; lowest number Footprint Expert Model Framework V3.0a of Carbon Trust) gave quite different emissions factors: 0.25–0.65 kg CO₂ per kilogram HFO.

Using the highest and lowest numbers for fuel use in overseas transport would give an impact of −4.8 to +4.6 % of the overseas transport GHG emissions or −2.9 to +2.1 % of the total CF. Using different emission factors for the other transports (e.g. boat trip from Germany to Norway and all road transports) would also give an impact on the total CF.

It is very difficult to make conclusions on the environmental impact of bananas compared to other fruits based on a comparison of the published data because of the differences in methodology and lack of transparency when it comes to assumptions and methodological choices. This has been illustrated by Mordini et al. (2009) who compared 35 CF studies on oranges and 31 CF studies on strawberries. Often, primary production was not reported or not adequately described. System borders were often not clear or defined differently. There seems to be a clear need for an internationally agreed calculation method for fruit products if the results shall be used for comparisons between fruits and between different producers of the same fruit.

Table 2 shows the CF results for a number of fruit products, including one banana study (Lescot 2012). The CF result for this study is similar to the CF by Lescot (2012), who also concluded transport to be the main contributor to the total GHG emissions. The primary production emissions reported here were also similar to the figures stated by Lescot (2012). Compared to other fruits, the primary production in this study is similar to one study of apples (Lillywhite et al. 2007), but slightly higher than a number of apple and orange CFs (Saunders et al. 2006). The CF for banana primary production seems to be much less than for kiwis and melons. The total CF result of the bananas from this study is higher than the CF for apple, grapes, peaches and mandarins. However, the results do not necessarily give the ranking of environmental performance between the different products because the quantification methodology may be different.

5.2 Primary production and processing

Generally, the CFs of agricultural produce from cradle to retail show a major contribution of emissions from the primary production phase, especially from N₂O and CH₄ (Garnett 2011). This case study does not follow this general trend due to the inefficient transport from Costa Rica to Norway which dominates the CF.

Table 2 Cradle-to-retail CF of bananas—distribution in life cycle stages and processes

Process	Values
Primary production	0.22
Primary production infrastructure	0.0023
Processing	0.017
Packaging	0.080
Transport to harbour	0.023
Harbour storage and handling, Moin	0.016
Overseas transport, pallet ships	0.75
Harbour handling, Hamburg	0.017
Transport from Hamburg to Kiel, truck	0.021
Transport from Kiel to Oslo, boat	0.059
Transport from Oslo harbour to Ulven ripening plant	0.004
Ripening at Ulven plant	0.008
Banana waste until wholesale, production	0.012
Transport to wholesale	0.006
Storage in wholesale	0.007
Transport to retail	0.008
Retail in Norway	0.038
Plastic bag used by some consumers	0.020
Banana retail waste, production	0.038
Cardboard box, retail waste	0.011
Banana retail waste	0.004
Plastic waste	0.002
Total	1.37

Methane emissions from landfill contributed 34 % of the primary production emissions and 5.5 % of the overall cradle-to-retail CF. In this study, the IPCC methodology was used (IPCC 2006c) to calculate landfill emissions, but there are other methodologies available (USEPA 1998, 2005; Machado et al. 2009). The method proposed by Machado et al. would have yielded an emission of only 11 g CO₂-eq per kilogram banana, whereas the IPCC method gave 66 g CO₂-eq per kilogram banana. Using the methodology by Machado et al. (2009) would have reduced the total primary production CF by 30 % and the cradle-to-retail CF by 4.8 %. No real-time measurements were made; hence, it is difficult to determine the extent of methane formation in the landfills.

Direct and indirect N₂O emissions were a major contributor to the CF in the primary production phase. It is important to note that the calculations for the N₂O emissions were made according to the IPCC guidelines (2006a), which do not have specific emission factors for the leaching of nitrate and ammonia from soil to water and air for tropical conditions. Due to the lack of calculation methods and the uncertainty of the calculations, the N₂O emissions may be underestimated.

An average yield from two plantations was used to calculate the CF. The two plantations did, however, have different

yields, leading to different results even though the same production technology and production guidelines were used in both plantations. Furthermore, data from one plantation showed that the yields varied significantly from year to year. This illustrates the problem of collecting representative data for a certain product. That large variations exist in biological systems is recognised, and recently, life cycle assessments with a timeline perspective have been published for agricultural crops (Vazquez-Rowe et al. 2012). Calculating GHG emissions for several years may be a good approach to give a more representative CF of a product.

5.3 Transport

Table 3 summarizes the global warming potential results of fruits in the literature. The CF of bananas produced in Costa Rica and sold in Norway is on the same level as other tropical fruits (kiwifruits: Xiloyannis et al. 2011; melons: Cellura et al. 2012), but higher than the CF of other fruit products found in the literature review (Saunders et al. 2006). The main reason for the high emissions is the overseas transport in boats. This is surprising because, in general, boat transport has been seen as being a relatively efficient form of transport, contributing little to the overall carbon footprint of products. For example, for apples, Saunders et al. (2006) calculated emissions of only 125 g/kg fruit even though the distance from New Zealand to Great Britain is far greater (17,840 km) than the distance from Costa Rica to Europe (9,400 km). The main reason behind the high emissions might be that the ships are rather small (10,000–20,000 deadweight tonnage, dwt) and that they return empty. If the transport emissions had been on the same level as for the NZ apples, the total CF would have been 0.75 kg CO₂-eq per kilogram product, a 45 % lower CF result.

5.4 Consumer

Including the plastic bag used by some consumers to package the bananas in the cradle-to-retail CF is not a simple choice. It can be seen as an element that is more linked to customer preference more than to the product. The fact that the packaging is provided in the shops and that there is a possibility that using the bag might reduce product wastage lead to the conclusion that the use of plastic bags should be included in the cradle-to-retail CF.

5.5 Possibilities for emission reductions

The main hot spot for bananas in this study is the overseas transport. By using refrigerated containers for the overseas transport and by transporting the bananas on container ship to Norway, instead of the current practice of boat transport to a harbour in Germany and road/boat transport onwards to

Table 3 Published CFP results for fruit products

Reference	Product	CF (kg CO ₂ -eq/kg product)	Study boundary
Luske (2010)	Banana	1.123	Cradle to retail
Lescot (2012)	Banana	0.324–1.124	
Mordini et al. (2009)	Oranges	0.08–0.33	Primary production
Davies et al. (2011)	Apples	0.21	Cradle to retail
Lillywhite et al. (2007)	Apples (UK)	0.18	Primary production
Saunders et al. (2006)	Apples (NZ)	0.185	Cradle to retail
Saunders et al. 2006	Apples (UK)	0.272	Cradle to retail
Yoshikawa et al. (2008)	Apples (Japan)	0.70	Cradle to retail
Xiloyannis et al. (2011)	Kiwifruit	1.74	Primary production

Oslo, a large reduction in the CF of the product can be achieved. The theoretical emission reduction was of the order of 51–66 % of the total transport impacts from the port in Costa Rica to arrival in Oslo, Norway, which is 33–42 % of the total cradle-to-retail CF. The largest reduction was calculated on the basis of large container ships (average >100,000 dwt) that carry all kinds of cargo and have a limited capacity for refrigerated containers, whilst the smaller reduction was calculated from emission figures from container ships that exclusively transport bananas. In both cases, it has been assumed that all containers return empty. This is a load factor of 50 %, which is a worst-case assumption because information on the return load was not available in this study. A load factor of 85 % would give a reduction in overseas transport emissions of 68–79 and 45–51 % in the cradle-to-retail emissions.

In the primary production phase, there is room for improvement regarding nutrient management. Bananas require large amounts of fertilisers (Soh 1997), but with precision agriculture, a reduction in mineral fertiliser use is possible, resulting in reduced GHG emissions (Trenkel 2010). The use of controlled-release mineral nitrogen in the form of granules could reduce the N₂O emissions by 31 %, which would result in an overall reduction of the primary production CF of 9 %. The results are based on an estimated reduction in mineral fertiliser use of 42 % when substituting traditional mineral nitrogen with controlled-release granules (Johnson 2012, personal communication).

The primary production including processing accounts for 16 % of the total CF. The impact of this phase could have been reduced by 30 % if methane emissions from the landfilled packaging plant waste were eliminated altogether, e.g. by some kind of biological treatment. Such treatment would, in most cases, give a product that could be sold on the market. The possibility of using banana waste for ethanol production was investigated by Graefe et al. (2011). The waste per hectare in this study was 3.24 tonnes, which, according to Graefe, could have yielded approximately 254 l ethanol. Graefe calculated the avoided emissions in

Costa Rica as 0.48 kg CO₂-eq per litre ethanol. The possible emission reduction was estimated to be 2.4 g CO₂ per kilogram banana. The reduction in emissions from eliminating methane emissions from processing plant landfills is much higher: 75 g CO₂-eq per kilogram banana.

5.6 Methodology

Carbon footprinting methodology is not a perfect method for assessing environmental sustainability and leaves many issues unresolved. It can, however, be a meaningful tool to assess global warming potential (Finkbeiner 2009). The methodology used in this study is based on the draft ISO 14067 (ISO 2012) and the LCA standards ISO 14040 (ISO 2006a) and 14044 (ISO 2006b). These standards leave a lot of freedom to make methodological choices.

In this study, system boundaries, allocation and inclusion of capital goods were important topics. In this study, the system ends when waste bananas, used packaging or any other waste is transported to a treatment facility except for landfilled waste, in which all emissions are allocated to this system. A calculation showed that if the reduced emissions due to the production of recycled material, biogas, energy and other possible useful products from waste treatment had been included, the CF would have been 1.5 % lower. The reason for ending the system before waste treatment is that it is difficult to determine what the recycled material will be used for, thus making it difficult to calculate avoided emissions. This means greater incentives for the subsequent user of the recycled material (or energy, compost, biogas, etc.) because the material would have lower associated emissions than the virgin material.

The alternative would be to include the reduced emissions from producing material or energy from waste treatment to the system that generates the waste. In that case, the system using the materials or energy would have to use the emissions from “virgin material production” or market average production of the type of energy, e.g. for electricity generated by a waste incineration facility, the emissions could be calculated from the grid average consumption mix.

If, however, the system generating the waste gets the credit from the recycled material and reclaimed energy and at the same time the system using the material and energy gets the benefit of using the low emission numbers for the waste treatment process, then there would be a case of double counting, i.e. the benefit of waste treatment would be counted twice. This could theoretically lead to an overestimation of the environmental benefit of the recovery processes compared to other measures to reduce environmental impacts.

Another issue of importance is whether or not production of infrastructure or capital goods should be included. The PAS 2050 (BSI 2011), the first global guideline on the calculation of CF, does not include the emissions from production of capital goods or their raw materials, but the PAS 2050-1 excludes some capital goods whilst taking others into account, such as the propping and transport infrastructure on the farm. The effect of excluding all infrastructure would have been a reduction of 4.4 % of the cradle-to-retail CF, whereas the effect of the PAS 2050-1 infrastructure exclusion would be slightly less, 4.2 %.

A number of allocation situations were encountered in this study. The first allocation occurs in the processing stage where bananas are sorted into premium quality, the lower quality going to baby food and waste. The waste is landfilled. Mass allocation was used between the premium and baby food bananas. The effect of using economic allocation instead of mass allocation would be an increase of 15 g CO₂-eq, giving an increase in the overall cradle to retail of only 1.1 %. The uncertainty seemed to be highest for the emissions from the transport from Kiel to Oslo in a passenger ship. If all emissions had been allocated to the cargo, the emissions would have added 333 g CO₂-eq to the CFP, i.e. 24 % of the cradle-to-grave CFP. There were no available data to enable the use of other allocation methods for transport from wholesale to retail, but since this transport contributes only 0.5 % of the cradle-to-retail CFP, the choice of allocation method is of minor importance to the overall result. The total emissions of the ship are allocated between passenger transport and cargo transport according to the share of the shipping company's share of income between the two. The problem with the economic allocation is that the income is determined not only by underlying physical factors such as the alternative cost for road transport, which correlates with emissions to a certain degree, but also by other factors less related to emissions, such as onboard entertainment.

The allocation between different cargos is a "ground area allocation". Data for emission per "lane meter" were given by the company. The ground area allocation is a variety of volume allocation assuming that the height and width of trucks are relatively similar. This allocation gives high emissions if the space is inefficiently utilized, which is reasonable,

but also high emissions for lightweight cargo which is reasonable as long as the limiting factor is volume.

6 Conclusions

The cradle-to-retail CF for Cavendish bananas produced in Costa Rica and sold in Norway was found to be 1.37 kg CO₂-eq per kilogram product, which equals 2.07 kg CO₂-eq per kilogram edible product. The corresponding numbers for the cradle-to-grave CF were 1.77 and 2.81 kg CO₂-eq per kilogram product. The result of the Dole Study from cradle to retail in Germany was 1.123 kg CO₂-eq per kilogram whole banana.

The impact of the primary production phase was 0.22 kg CO₂-eq per kilogram product, which is not high compared to other fruit products. The main contributor to total CF was overseas transport from Costa Rica to Germany, 55 %. The main reason for the high impact of overseas transport is that the ships have a small load capacity and that they return empty to Costa Rica.

The main potential for reducing the GHG emissions lies in using alternative forms of overseas transport. By exchanging pallet ships for container transport, the total CF may be reduced by 33–42 % depending on the size of ship that is used. If the waste generated at the packaging plant had been treated aerobically instead of landfilled, a reduction of the CF by 5.5 % would have resulted. One such possibility could have been converting the waste into ethanol, which would have given a further reduction of 0.2 %. The use of mineral fertiliser from plants with a N₂O catalyser could reduce the CF by a further 9 %.

The methodology was important for the end result. This study gave significantly higher cradle to retail than Luske (2010) using the same background data. This could only, to a small degree, be explained by the longer transport distances to Norway than Germany and the fact that this study contained farm infrastructure and packing plant landfill, which Luske did not include.

System boundaries give very different results depending on which life cycle stages are included, as shown above, but also depending on which unit processes are included. Allocation issues were also important for the final result, especially the allocation of the Kiel–Oslo passenger boat emissions. The inclusion of capital goods made a significant difference (>1 %) for the end result.

The main uncertainties of the CF result are connected to N₂O emissions from agriculture, methane emissions from landfills, use of secondary data (especially fuel production emissions) and variability in the primary production data.

A major uncertainty of the cradle-to-grave CF is the consumer banana wastage rate. This rate is known to be high (WRAP 2008), and this study shows that the impact on

the CF is significant. The number of consumers is large and the behaviour can vary considerably between consumers, so it is very unlikely that representative primary data ever will be collected for the wastage rate.

There is a need for an internationally agreed calculation method for bananas and other food products if CFs are to be used for comparative purposes. The standardisation should cover important methodological issues like system boundaries (capital goods, between-product systems when materials cross them), allocation (including the question of whether it is necessary to use the same allocation method throughout a study), soil carbon change and carbon in standing biomass, and directions on the use of secondary data.

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